Floor-integrated HVAC-systems for zonal supply of multifunctional buildings

Speakers:
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Abstract: *Planning periods and utilization scopes, especially for commercial buildings, are getting shorter and future applications are harder to predict because of quickly changing social, demographic and economic conditions. That is why future sustainable buildings do not only need to be energy efficient, they also require a very high level of multifunctionality. They should provide modular flexibility as well as scalability and adaptability to the changing requirements. An innovative wide-span floor system enables an easy reconfiguration of building zones and the implementation of a modular floor-integrated heating-, ventilation- and air-conditioning-concept (HVAC). Here, the supply systems are particularly selected for the required supply situation of the separate building zones. Small and lightweight supply units with low power outputs have to be chosen to enable an independent supply for all possible zone types. Thereby, the combination of concrete core activation, underfloor ventilation system and heat pump represents a promising supply to meet the demand of different usage scenarios.*

Sustainable Building Design, HVAC, Modular Supply Systems, Multifunctional Buildings

Introduction

Construction and operation of buildings are responsible for approx. 40 % of the overall energy consumption and the resulting CO_2-emissions in the European Union [1]. Consequently, efficiency improvements in design, construction, utilization and operation have a huge impact on the energy demand during a buildings' lifecycle. Furthermore, even in industrialized countries the majority of contemporary buildings are used mono-functionally and do not take into account the dynamic requirements of today's user profiles (e.g. change of use, technological developments, demographic changes). This often leads to the necessity to demolish or substantially restructure such buildings long before they reach the end of their economic lifetime. In order to increase the usage efficiency and to exploit the buildings' full lifetime, adaptive structural systems with a high degree of flexibility have to be developed. Therefore, within an interdisciplinary project focusing on sustainable buildings of the future, a new and very adaptable approach to the construction of buildings and the design of supply systems is developed. Particularly, a concept for flexible floor slab integrated supply units is developed and its feasibility is analyzed.

Within the performed analysis, necessary HVAC components and their required capacities for different usage scenarios (residential and offices) are determined. Based on this information, technically and economically feasible scenarios for supply component distribution within the floor slab structure are evaluated. Finally, a concept for standardized box-like exchangeable supply units is developed. These supply units require interoperability, scalability and common interfaces for control as well as connections with further facility infrastructure. Such a system could be dynamically reconfigured and adapted to changing technologies and requirements, thus enhancing usability as well as decreasing the lifecycle energy demand of the building.

Concept

With the aim of implementing a sustainable and multifunctional building concept in practice, an entirely flexible building structure with exchangeable wall and facade elements for new buildings is required. As shown in fig. 1, applying the same building area for different office or residential scenarios is possible. Matching this concept, modular supply units integrated in an innovative floor slab system allow dynamic adaptions to changing requirements.

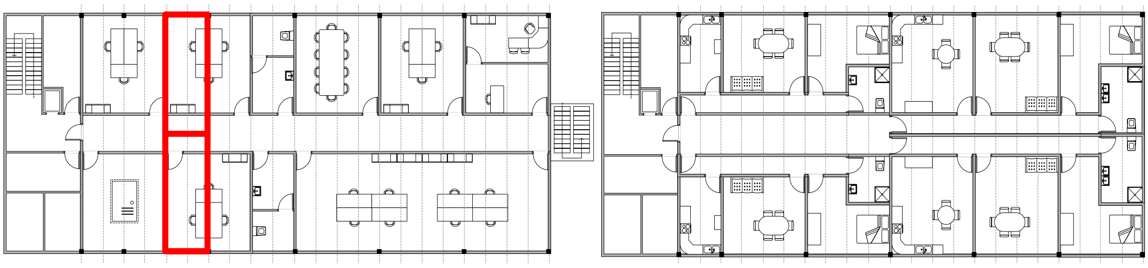

Fig. 1*: Exemplary floor plan of an office (left) and a residential building (right)*

Design principles for integrated floor slabs

The floor slabs need to provide high flexibility and adaptability in order to allow conversions and changes of use without significant modification of the building structure. Floor slabs do not only fulfill load-bearing and bracing functions; they create the separation between adjoining functional units and hence influence the planimetry, the installation of building services as well as physical properties of the building. In [2] a requirement profile for integrated floor slabs has been compiled that includes the most important factors in the fields of structural engineering, architecture, manufacturing, flexibility, fire protection, building physics, dismantling and recycling. One possibility to design multifunctional slab systems is to break up the conventional additive ceiling assembly (flooring, building services/ installations, suspended ceiling) and to dissolve the compact cross sections of conventional floor slabs into wide-span, multi-web structures. Essential properties of such integrated floor slab solutions are [3]:

- Complete and reversible integration of building services in the load-bearing structure with access from the top of the floor slab or through the facade to its installation cavity;
- Provision of bearing capacity reserves, large spans and waiving of intermediate supports in order to achieve maximum flexibility of use;
- High degree of prefabrication and use of detachable steel connections for ease of extension, short building times, components' reuse and building recycling;
- Continuous concrete slab for thermal efficiency and ensuring fire safety of the structure.

Development of an integrated floor slab system

Based on the design principles described above, an innovative integrated floor slab system has been developed. With spans of up to 16 m and width of 2.50 m (red line in fig. 1) as well as a bearable service load of 5 kN/m² the slab system offers a high degree of flexibility the zone design a usage (fig. 2). The detailed load bearing and deformation behavior of the floor-slab elements is presented in [4 - 6]. The slab system features an internal cavity of 0,5 m, which enables the complete integration of building services in the load-bearing structure (fig. 2).

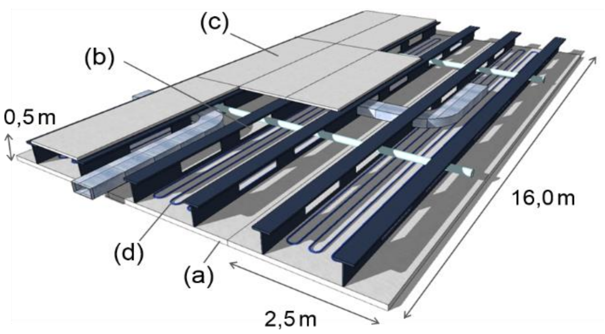

Fig. 2 *Integrated composite floor-slab system with (a) prestressed concrete slab, (b) large web openings, (c) removable cover panels, (d) integrated cooling lines*

Large web openings in the steel profiles allow a variable and adaptable routing even for ventilation ducts with large diameters (fig. 2 (b)). However, the demand for such web openings decreases with the level of supply system decentralization. Therefore structural efficiency of the floor slab can be further improved by reducing the size of the initially designed web openings. Ease of access to the supply systems within the floor and a convenient installation and maintenance of these components "from above" is achieved by the use of removable cover panels placed on top flanges of the steel profiles (fig. 2 (c)). Alternatively, installation and maintenance through flexible and exchangeable facade panels would be possible. This would reduce user impairment and increase maintenance flexibility. To improve the thermal comfort and energy efficiency of the enclosed living/working areas, the floor slab is equipped with integrated heating and cooling networks for thermal activation (fig. 2 (d)). The concrete slab thus determines the thermal performance of the floor slab system [7]. By its thickness of 10 cm the continuous slab additionally fulfills the fire safety requirements in the event of fire exposure from the underside. At the end of its lifetime the integrated slab system allows for an easy dismantling and reuse of single components as well as for a building recycling by means of detachable connections and joints. Instead of conventional material recycling, building recycling enables to employ the structure of a building over several cycles of use.

Demand Scenarios

The heating and cooling loads are calculated with SOLAR COMPUTER[1] for an exemplary building (fig. 1) in accordance with DIN EN 12831 [8] and VDI guideline 2078 [9]. The calculation of the air requirement is based on DIN 1946-6 [10] for dwellings and on EN 13779 [11] and EN 15251 [12] for commercial buildings. The results for specific rooms are shown in tab. 1. These are approximate values based on typical configuration assumptions of the building and the rooms (i.e.: heat transfer coefficient, size, internal/external loads).

[1] The German software SOLAR COMPUTER enables calculations and design development for technical building systems, architecture and facility management.

	Length	Width	Heating load		Cooling load		Air requirement	
	m	m	W/m²	kW	W/m²	kW	m³/h	1/h
Executive office	5.75	5.00	38.0	1.1	36.0	1.0	122.9	1.4
Group office	5.75	5.00	38.0	1.1	53.0	1.5	148.1	1.7
Open-plan office	5.75	15.00	38.0	3.3	59.0	5.1	419.0	1.6
Conference room	5.75	5.00	38.0	1.1	45.0	1.3	324.5	3.6
Server room	5.75	5.00	28.0	0.8	355.0	10.2	97.7	1.1
WC	5.75	2.50	38.0	0.5	14.0	0.2	61.4	1.4
Living-/bedroom	5.75	5.00	38.0	1.1	19.0	0.5	53.6	0.6
Kitchen	5.75	5.00	38.0	1.1	105.0	3.0	53.6	0.6
Bathroom	3.95	2.50	58.0	0.6	74.0	0.7	53.6	1.7

Tab. 1*: Heating and cooling loads and air requirements of specific rooms*

Supply Scenario

The unconventional installation of the supply system makes the choice of adequate and efficient HVAC-components difficult. A compact (small and light) multifunctional plant construction is necessary. All supply units must be capable of covering the loads presented in tab. 1. Therefore, the baseload for heating and cooling operation is delivered through concrete core activations (CCA), however, the specific thermal demand of each zone needs to be provided additionally by radiator or ventilation systems. As shown in fig. 1, the CCA in each floor slab is divided lengthwise into two separately supplied zones and each room consists of at least one of these half-slabs. To prove the feasibility of the concept the suitability for floor integrated installation is analyzed for some of the most typical supply systems. Following, in tab. 2 and 3, main characteristics resulting from a detailed analysis are presented.

	Characteristics	Size-critical components	Infrastructure connections
Thermal activation	Slow system, floor-ceiling connection	-	Water supply, return flow
CHP Fuel cell	Heat-controlled	Heat exchanger, inverter	Gas, supply air, exhaust gas, condensat removal
CHP Stirling engine	Heat-controlled	Stirling engine	Gas, exhaust gas
CHP Combustion engine	Heat-controlled	Combustion engine	Gas, supply air, exhaust air, condensat removal
Condensing boiler	-	-	Gas, supply air, exhaust gas, condensat removal
Heat pump	Air-water system, heating and cooling	Evaporator, fan	Supply air, exhaust air
Chilled water unit	Air-cooled	Heat exchanger	Water supply, return flow supply air, exhaust air
Ventilation system	Underfloor-installation	Heat exchanger	Water supply, return flow supply air, exhaust air

Tab. 2*: Characteristics and requirements of the analyzed supply systems*

	Heating capacity	Cooling capacity	Volume	Weight	Sound pressure level
	kW	kW	m³	kg	dB
CHP Fuel cell	0.6	-	0.25	120	30
CHP Stirling engine	3	-	0.21	110	45
CHP Combustion engine	2.5	-	0.43	100	46
Condensing boiler	0.9	-	0.11	33	42
Heat pump	2.8	2.7	0.14	55	35
Chilled water unit	-	1.4	0.13	46	48
Ventilation system	0.4	0.28	0.12	40	39
Thermal activation	33*	40*	entire slab	-	30

Tab. 3*: Technical details for the analyzed supply systems (minimal values of different manufacturers) [13]-[21]* * W/m²

Discussion

The particular loads of single half-slabs for the analyzed specific demand scenarios (tab. 1) are shown in fig. 3 together with the minimal capacities of the evaluated supply scenarios (from tab. 3). As it can be seen, most systems (except CHP fuel cell and condensing boiler) have to supply at least two or more half-slabs. Thus, adequately aggregated supply zones have to be built in order to guarantee an efficient supply concept; except for specific high requirement zones as conference or server rooms. To reduce the risk of failure and to extend the units' lifetime the number of clocking cycles should be minimized through the installation of buffer storages. Again, the aggregation of rooms with similar supply demands into larger supply zones can help to maximize the full load operation hours and minimize the required buffer storage capacities.

It has to be guaranteed that negative user impacts are avoided. In this context, according to DIN 4109 [22] the maximum sound pressure level of 30 dB in living- or bedrooms is acceptable. For systems with higher sound levels, compact insulation materials with low thicknesses can be installed, as presented in [23]. Moreover, solid-borne sound insulation is essential for all systems. Furthermore, sufficient air supply for ventilation purposes as well as for the supply of combustion processes, heat pumps and water chillers might be critical. If the aesthetic design of the building does not allow air supply openings in regular distances in the facade, the installation of a central air shaft within the floor slab could be realized. As seen in fig. 2b, the required cross-slab ducts can be easily incorporated in the floor slab concept.

The evaluation of the system size is complex since new individual plants, which are designed according to the available installation space, have to be developed. Still, it can be assumed that the required volumes stay constant when adapting the single components to the limited height of the floor.

Based on this fact, the CHP combustion engine (as the biggest plant, see tab. 3) needs nearly 1.5 m² of the floor space, expecting a plant height of 30 cm (leaving 20 cm for the floor panel covering, supply system mountings, ducts, insulation etc.).

As mentioned above, the floor slab system offers a bearable service load of 5 kN/m². Based on DIN EN 1991 [24], a minimum load of 2 kN/m² has to be guaranteed in office and residential buildings. Thus, the supply systems and the associated fixing materials, ducts and insulation should not exceed 3 kN/m². All the analyzed components match this requirement.

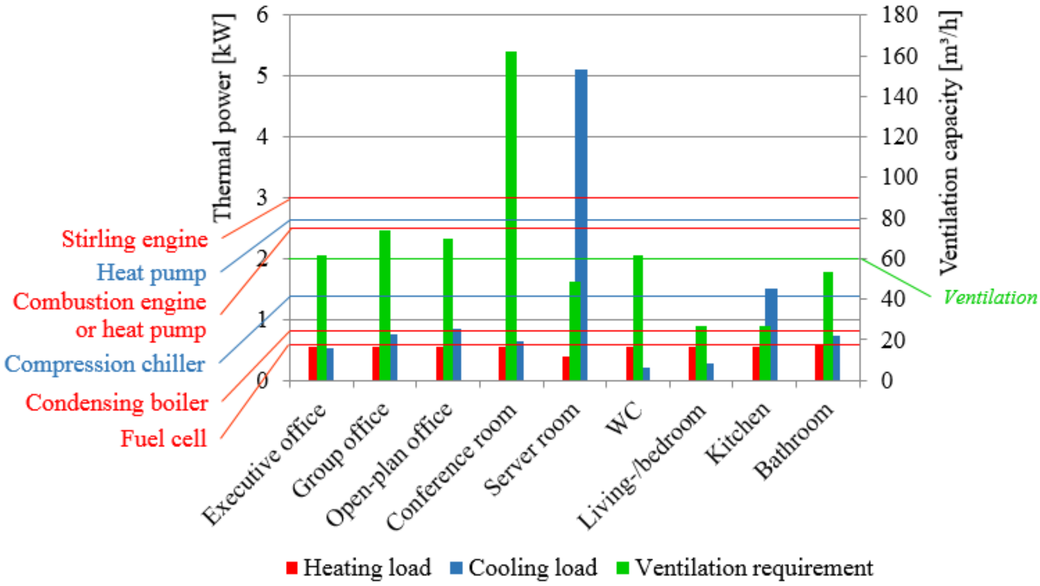

***Fig. 3**: Loads for a half slab of a specific room type and minimal capacities of the analyzed supply systems*

Conclusion

Within the performed analysis, demand scenarios of typical office and residential buildings were defined and feasible supply scenarios were deduced. It was shown that the smallest possible supply units have to be chosen because of size- and weight-limitations and that constraints concerning possible numbers of clocking cycles have to be considered. Taking these boundary conditions into account, concrete core activation (supplying the heating and cooling baseload), an underfloor ventilation system and a heat pump (combined heating and cooling mode) turn out to be the best configuration option.

In conclusion, the described floor-integrated supply concept offers several advantages compared to conventional buildings. Modular floor slab systems consider dynamic requirements of different user profiles and make multi-functional building designs possible. Variation of use is possible as well as adaption to technological development. Demand and supply scenarios are optimally adjusted. Furthermore, the building's full range of lifetime is exploited and due to the easy replacement of inefficient components the lifecycle energy demand is decreased. Next, the dimensioning and operation performance of the supply systems have to be verified through dynamic simulations. Furthermore, an economic analysis of the presented approach in comparison to conventional building supply methods has to be performed.

References

[1] Spitalny, L. et al. (2014). Estimation of the economic addressable market of micro-CHP and heat pumps based on the status of the residential building sector in Germany. *Applied Thermal Engineering*

[2] Classen, M.; Gallwoszus, J.; Hegger, J.; et al.: Sustainability assessment of long span floor systems. Bauingenieur Volume: 89 Pages: 125-133, März 2014

[3] Dressen, T.; Classen, M.: Deformation of reinforced and prestressed concrete beams with large webopenings. Beton- und Stahlbetonbau, Vol. 108 (7) 2013, pp. 462-474

[4] Hegger, J. et al.: Multifunctional composite slab system with integrated building services. STAHLBAU Volume: 83, Juli 2014, S. 452–460

[5] Hegger, J.; Schaumann, P; Feldmann, M.: Entwicklung einer integrierten Verbunddecke für nachhaltige Stahlbauten, Stahlbau 82, Januar 2013, pp. 11-17

[6] Classen, M.; Gallwoszus, J.; Hegger, J.; et al.: Load-bearing behavior of an integrated composite floor system. Bauingenieur Vol. 89, (3) 2014, pp. 91-101

[7] Feldmann, M.; Pyschny, D.; Döring, B.: Investigation of thermal performance of the innovative multifunctional composite floor system. Bauingenieur Vol. 89, (3) 2014, pp. 116-124

[8] DIN EN 12831:2003-08, Heating systems in buildings – Calculation of the design heat load

[9] VDI-Guideline 2078:2012-08, Cooling Load Calculation of Air-conditioned Rooms

[10] DIN 1949-6:2009-05, Ventilation and air conditioning – Part 6: Ventilation for residential buildings

[11] DIN EN 13779:2007-09, Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems

[12] DIN EN 15251:2012-12, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

[13] elcore. Elcore 2400. Available: online. http://www.elcore.com [accessed: 17.04.2014]

[15] SENERTEC. The Dachs. The Microcogeneration. Technical Data. Available: online. http://www.senertec.de/en/derdachs.html [accessed: 22.04.2014]

[16] Vaillant. Kraft-Wärme-Kopplung. ecoPOWER 1.0. Available: online. http://www.vaillant.de/ecopower [accessed: 22.04.2014]

[17] elco. THISION S. Available: online. http://www.elco.de/produkte/thision.html [accessed: 01.03.2014]

[18] Vaillant. Gas-fired wall hung condensing boilers. ecoTec plus. Available: online. http://www.vaillant.com [accessed: 15.05.2014]

[19] Vaillant. geoTHERM. VWL 35/4. Installations- und Wartungsanleitung. Available: online. http://www.vaillant.de [accessed: 15.05.2014]

[20] Rehsler Kühlsysteme. TAE evo. Available: online. http://www.rehsler-kuehlsysteme.de [accessed: 21.05.2014]

[21] TROX Technik. Air-Water Systems. Decentralised Ventilation 2014. Available: online. http://www.trox.de/en [accessed: 24.03.2014]

[22] DIN 4109:2012-08, Sound insulation in buildings; requirements and verifications

[23] WOLF Bavaria. Professional Sound Insulation. Available: online. http://www.wolf-bavaria.eu [accessed: 05.05.2014]

[24] DIN EN 1991-1-1/NA:2010-12, National Annex – Part 1-1: General actions – Densities, self-weight, imposed loads for buildings